CHAPTER 8

SPACE TOWERS

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Abstract: The author proposes two new revolutionary macro-engineering projects: inflatable pneumatic high altitude towers (height up to 100 km) and kinetic cable space towers (height up 160,000 km). The second method allows building of space elevator without rocket flights to space. Related to the first macro-project, the author provides theory and computations for building inflatable space towers. These macro-projects are not expensive and do not require rockets. They require thin strong films composed of artificial fibers and fabricated by current industry. They can be built using present technology. Towers can be used (for tourism, communication, etc.) during the construction process and provide self-financing for further construction. The tower design does not require outdoor work at high altitudes; all construction can be done at the Earth's surface. The transport system for a tower consists of a small engine (used only for friction compensation) located at the Earth's surface. The tower is separated into sections and has special protection mechanisms in case of damage. Related to the second macro-project, the author discusses a revolutionary new method to access outer space. A cable stands up vertically and pulls up its payload into space with a maximum force determined by its strength. From the ground the cable is allowed to rise up to the required altitude. After this, one can climb to any altitude using this cable or deliver a payload at altitude. The author shows how this is possible without infringing the law of gravity. The Section 2 contains the theory and computations for four macro-projects (towers that are 4, 75, 225 and 160,000 km in height, respectively). The first three macro-projects use the conventional artificial fiber produced by current industry, while the fourth project requires nanotubes currently made in scientific laboratories. The chapter also shows in a fifth macro-project how this idea can be used to launch a load at high altitude

Keywords: space tower, pneumatic tower, cable tower

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1. PNEUMATIC SPACE TOWERS

1.1 Introduction

The idea of building a tower high above the Earth into the heavens is very old. The writings of Moses, about 1450 BC, in Genesis, Chapter 11, refer to an early civilization that in about 2100 BC tried to build a tower to heaven out of brick and tar. This construction was called the Tower of Babel, and was reported to be located in Babylon in ancient Mesopotamia. Later in chapter 28, about 1900 BC, Jacob had a dream about a staircase or ladder built to heaven. This construction was called Jacob's Ladder (Smitherman, 2000). More contemporary writings on the subject date back to K.E. Tsiolkovski (see his manuscript "*Speculation about Earth and Sky and on Vesta*," published in 1895; Tsiolkovski, 1959). This idea inspired Sir Arthur Clarke to write his novel, *The Fountains of Paradise* (Clarke, 1978) about a space tower (elevator) located on a fictionalized Sri Lanka, which brought the concept to the attention of the entire world. Landis and Catarelli (1999) re-examined Tsiolkovski tower. The Russian scientist G. Pokrovskii (1964) suggested a rigid conic tower of height 160 km having a base diameter 100 km and filled by hydrogen.

Today, the world's tallest construction is a television transmitting tower near Fargo, North Dakota, USA. It stands 629 m high and was built in 1963 for KTHI-TV. The CNN Tower in Toronto, Ontario, Canada is the world's tallest building. It is 553 m in height, was finished in 1975, and has the world's highest observation deck at 447 m. The tower structure is concrete up to the observation deck level. Above is a steel structure supporting radio, television, and communication antennas. The total weight of the tower is 3,000,000 tons. The Ostankin Tower in Moscow is 540 m in height and has an observation desk at 370 m. The world's tallest office building is the Petronas Towers in Kuala Lumpur, Malasia. The twin towers are 452 m in height.

Current materials make it possible even today to construct towers many kilometers in height. However, conventional towers are very expensive, costing tens of billions of dollars. When considering how high a tower can be built, it is important to remember that it can be built to any height if the base is large enough.

The pneumatic towers proposed in this chapter are cheaper by factors of hundreds. They can be built on the Earth's surface and their height can be increased as necessary. Their base is not large. The main innovations in this macro-project are the application of helium, hydrogen, or warm air for filling inflatable structures at high altitude and the solution of a stability problem for tall (thin) inflatable columns, and utilization of new artificial materials (Bolonkin, 2002d, 2003i).

The inflatable high towers (3–100 km) have numerous applications for government and commercial purposes:

- Entertainment and observation platform.
- Entertainment and observation deck for tourists. Tourists could see over a huge area, including the darkness of space and the curvature of the Earth's horizon.

- Drop tower: tourists could experience several minutes of free-fall time. The drop tower could provide a facility for experiments.
- A permanent observatory on a tall tower would be competitive with airborne and orbital platforms for Earth and space observations.
- Communication boost: A tower tens of kilometers in height near metropolitan areas could provide much higher signal strength than orbital satellites.
- Solar power receivers: Receivers located on tall towers for future space solar power systems would permit use of higher frequency, wireless, power transmission systems (e.g. lasers).
- Low Earth orbit (LEO) communication satellite replacement: Approximately six to ten 100-km-tall towers could provide the coverage of a LEO satellite constellation with higher power, permanence, and easy upgrade capabilities.

Further methods proposed by the author for access to space are given in the references (Bolonkin, 2002–2005).

1.2 Concept Description

1.2.1 Design of pneumatic tower

The simplest tourist tower includes (Fig. 1): inflatable column, top observation deck, elevator, stabilizing cables, and control pressure and stability. The tower is separated into sections by horizontal and vertical partitions (Fig. 2) and contains entry and exit air (gas) hoses and control devices.

1.2.2 Used gas

The compressed air which fills in the pneumatic tower is the heaviest part of the tower. Air density decreases at high altitude and it cannot support a top tower load. The author suggests filling the towers with a light gas, for example, helium, hydrogen, or warm air. Suggested tower design provides filling up by gas in any section in any time (see item 13, 14 in fig. 2).

The computations for changing pressure of air, helium and hydrogen are presented in Fig. 3 of Bolonkin (2003i) (see also Eq. 1 in this chapter). If all the gases have the same pressure (0.11 MPa, 1.1 atm) at Earth's surface, their columns have very different pressures at 100 km altitude.

Air has the pressure 0 atm, hydrogen – 0.4 atm (0.04 MPa), and helium – 0.15 atm (0.015 MPa). A pressure of 0.4 atm means that every square meter of a tower top can support 4 tons of useful loads. Helium can support only 1.5 tons (Bolonkin, 2003i, Fig. 3).

Unfortunately, hydrogen is dangerous as it can burn. The catastrophes involving dirigibles are sufficient illustration of this. Hydrogen can be used only above an altitude of 13–15 km, where the atmospheric pressure decreases by 10 times and the probability of hydrogen burning is small.

The average temperature of the atmosphere in the interval from 0 to 100 km is about 240 °K. If a tower is made of dark color material, the temperature inside the tower will

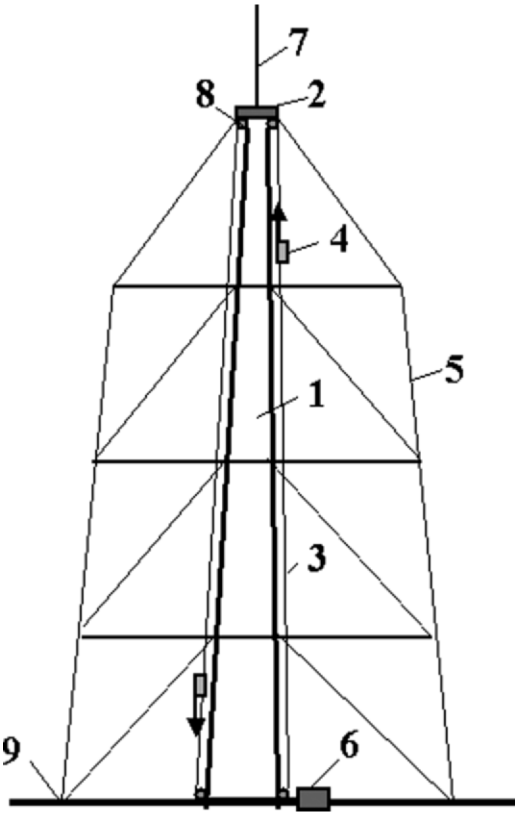

Figure 1. Pneumatic tower of height 3 km. 1 – Inflatable column of radius 5 m; 2 – observation desk; 3 – load cable elevators; 4 – passenger cabins; 5 – stabilizing cables; 6 – engine; 7 – radio and TV antenna; 8 – rollers of cable transport system; 9 – stability control

be higher than the temperature of the atmosphere at a given altitude in day time, so that the tower support capability will be greater (see Eq. 1).

The observation radius versus altitude is presented in (Bolonkin, 2003i, Figs. 4–5), (see also Eq. 23 in this chapter).

1.2.3 Construction material

The author relies only on old information about textile fiber for inflatable structures (Harries, 1973). This refers to DuPont textile Fiber B and Fiber PRD-49 for tire cord. They are six times as strong as steel (maximum tensile stress is $312\,\mathrm{kg/mm^2}$) with a specific density of only 1.5 g/cc, and ultimate elongation is 4% (B) and 1.8% (PRD-49).

The tower parameters vary, depending on the strength of the textile material (film), specifically the ratio of the safe tensile stress σ to specific density γ. Current industry widely produces artificial fibers that have tensile stress

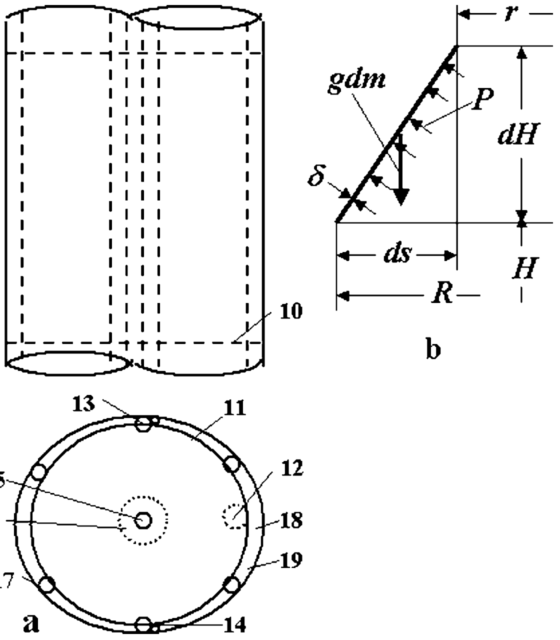

Figure 2. (a) Section of pneumatic tower. Side view is in top of figure, cross section area is in lower part of figure. 10 – horizontal film partitions; 11 – light internal film (internal cover, membrane); 12 – free fly air balls which close a hole when the cover is damaged; 13 – entrance line (hose) of compression air (gas) and pressure control; 14 – exit line (hose) of air and control; 15 – control laser beam; 16 – sensors of laser beam location; 17 – control cables and devices; 18 – section volume, 19 – tower cover (film, casing, membrane). (b) Scheme for computation an optimal tower cone and a tower cover thickness

σ = 500–620 kg/mm^2 and density $\gamma = 1800\,\mathrm{kg/m^3}$. The ratio of these quantities is $k = \sigma/\gamma$ or $K = \sigma/\gamma/10^7 = 0.28{-}0.34$ $[(\mathrm{m^2/s^2})/10^7]$ (Using the ratio K is more convenient, because it is seven order of magnitudes lower than k). There are whiskers (in industry) and nanotubes (in scientific laboratories) with $K = 1$–2 (whisker) and $K = 5{-}11$ (nanotubes). Theory predicts fiber, whisker and nanotubes could have K values ten times greater (Galasso, 1989; Dresselhous, 2000; Carbon Fibers, 1995).

The tower parameters have been computed for $K = 0.05 - 0.3$ (Bolonkin, 2002, 2003), with a recommended value of $K = 0.1$.

1.2.4 Safety of tower

One may think that inflatable construction is dangerous, on the basis that a small hole (damage) could deflate the tower. However, this assumption is incorrect. The tower may be built with multiple vertical and horizontal sections, double walls (covers, membranes), and special devices (e.g. air balls) which will temporarily seal a hole. If a tower section sustains major damage, the tower height is only decreased by one section. This modularity is similar to combat vehicles – bullets may damage its tires, but the vehicle continues to operate. The special hoses and devices control and support the tower internal pressure. If surface cover is damage, the internal film temporary closes the hole.

1.2.5 Stability of pneumatic tower

Stability is provided by stabilizing cables (tensile elements). The verticality of the tower can be checked by laser beam and sensors monitoring beam location (Fig. 2). If a section deviates from vertical control cables, control devices, and pressure changes restore the tower position. The stabilizing cables also support the tower in a windy weather.

1.2.6 Tower design

The tower building will not have conventional construction problems such as lifting building material to high altitude. All sections are identifiably. New sections are put in at the bottom of the tower, the new section is inflated, and the entire tower is lifted. It is estimated the building may be constructed in 2–5 months. A small tower (up to 3 km) can be safety located in a city. The tower may be illuminated by color lights and it can be the city symbol.

1.2.7 Estimation of tower cost

The pneumatic tower does not require high-cost building materials. The tower will be a hundred times cheaper than conventional solid towers 400–600 m tall.

1.3 Theory of Pneumatic Towers

Equations developed and used by author for estimations and computation are provided below (in the metric system).

1.3.1 The pressure of gas

The given molecular weight, μ, the temperature, T, of an atmospheric gas mixture, the gravitational acceleration, g, and the atmospheric pressure, $P(H)$, versus altitude, H, may be calculated by using:

$$(1) \qquad P = P_0 \exp\left(-\frac{\mu g H}{RT}\right) \qquad \text{or} \qquad P_{\mathrm{r}} = \frac{P}{P_0} = \exp(-aH),$$

where P_o is the pressure at the planet's surface (for the Earth $P_o \approx 10^5$ N/m^2), $R = 8314$ J/(kmol·K) is ideal gas constant and P_r is a relative (dimensionless) pressure. For air: $\mu = 28.96$ kg/kmol, for hydrogen: $\mu = 2$ kg/kmol, for helium $\mu = 4$ kg/kmol. Also, $g = 9.81$m/s^2 and $a = \mu g/(RT)$.

1.3.2 Optimal cover thickness and tower radius (optimal variable tower cone)

Let us consider a small horizontal cross-section of a tower element (fig. 2b). Using the known formulas for mass and stress, we write

$$(2) \qquad Pds = gdm,$$

where

$$(2a) \qquad \begin{aligned} &dm = 2\pi\ r\gamma\delta\ dH, \qquad ds = \pi(R^2 - r^2), \\ &R = r + dr, \qquad ds \approx 2\pi r\ dr. \end{aligned}$$

Here, m – the mass of the cover (i.e. the membrane which holds the internal pressure), γ – cover specific mass [kg/m^3], σ – cover tensile stress [N/m^2], s – tower cross-section area which supports a tower cover [m^2], $R = R(H)$ – external radius of tower [m] at height H (r is tower radius at height $H + dH$ – see Eq. 2a), P is the extra internal gas pressure over outside atmosphere pressure, while *ds, dm, dH, dr* are differentials of *s, m, H, R,* respectively. The optimal cone shape of the tower is such that the internal pressure supports the tower cover at any altitude H.

Substituting the above formulas in Eq. (1), one gets

$$(3) \qquad Pdr = g\gamma\delta\ dH.$$

From equations for stress we find the cover thickness, δ [m],

$$(4) \qquad 2\pi RPdH = 2\delta\sigma\ dH \qquad \text{or} \qquad \delta = \frac{\pi RP}{\sigma}.$$

If we substitute Eq. (4) in Eq. (3) and integrate, we find

$$(5) \qquad R = R_0 \exp\left(-\frac{\pi g H}{k}\right) \qquad or \qquad R_r = \frac{R}{R_0} = \exp\left(-\frac{\pi g H}{k}\right),$$

where R_r is relative (dimensionless) radius and R_o is base tower radius.

1.3.3 Computation of tower lift force F

The tower lift force can be computed by using the relationships:

$$(6a) \qquad F = PS, \qquad S = S_r S_0,$$

where

$$(6b) \qquad S_r = \frac{\pi\,(R_r R_0)^2}{S_0}, \qquad S = S_0 R_r^2.$$

Substituting Eq. (6b) in Eq. (6a), we got finally

$$(7) \qquad F = PS_0 R_r^2,$$

where $S_o = \pi R_o^2$ is a cross-section tower area at $H = 0$, $S_r = S/S_o$ is the relative (dimensionless) cross-section of the tower area, $S = S(H)$ is a variable cross-section tower area at H. If we substitute Eqs. (1) and (5) in Eq. (7) we find

$$(8) \qquad F = P_0 S_0 \exp\left[-(a + \frac{2\pi g}{k})H\right] \quad \text{or} \quad F_r = \frac{F}{P_0 S_0} = \exp\left[-(a + \frac{2\pi g}{k})H\right],$$

where F_r is the relative (dimensionless) force.

1.3.4 Tower base area

Now we intend to estimate the tower base area for a given top load W [kg]. The required base area S_o (and the associated radius R_o) for given top load W may be found from Eq. (8) under the condition $F = gW$:

$$(9) \qquad P_0 S_0 = \frac{gW}{F_r(H_{\max})} \qquad \text{and} \qquad R_0 = \left(\frac{S_0}{\pi}\right)^{1/2}.$$

1.3.5 Mass of tower cover

From Eqs. (2) and (2a) we get

$$(10) \qquad dm = 2\pi R \gamma \delta dH.$$

If we substitute Eqs. (1), (4) and (5) in Eq. (10) we find

$$(11) \qquad dm = \left(\frac{2\pi}{k}\right) P_0 S_0 \exp\left[-(a + \frac{2\pi g}{k})H\right] dH.$$

Integrate this relation from H_1 to H_2, we get the mass M [kg].

$$(12) \qquad M = \frac{2\pi P_1 S_1}{k}\left(a + \frac{2\pi g}{k}\right)\left[F_r(H_1) - F_r(H_2)\right],$$

and the relative (dimensionless) mass (for $H = 0$) is

$$(13) \qquad M_r = \frac{M}{P_0 S_0} = \frac{2\pi}{k}\left(a + \frac{2\pi g}{k}\right)(1 - F_r).$$

1.3.6 The thickness of cover

The cover thickness may be found from Eqs. (4), (5) and (1)

$$(14) \qquad \delta = \frac{\pi}{\gamma k} P_0 R_0 \exp\left[-\left(a + \frac{2\pi g}{k}\right)H\right].$$

The relative (dimensionless) cover thickness is

$$(15) \qquad \delta_r = \frac{\delta}{P_0 R_0} = \frac{\pi}{\gamma k}\exp\left[-\left(a + \frac{2\pi g}{k}\right)H\right].$$

1.3.7 Computation of bending moment

A wind tries to bend the tower. The maximum safety bending moment which the tower can keep is found using the relations [see Eqs. (8) and (5)]

$$M_{\mathrm{b}} = FR = R_0 P_0 S_0 R_r F_r \tag{16}$$

and the relative (dimensionless) bending moment is

$$M_{b,r} = \frac{M_b}{R_0 P_0 S_0} = R_r F_r. \tag{17}$$

1.3.8 Estimation of gas mass M_g into tower

Let us write the gas mass in a small volume and integrate this expression for altitude:

$$dm_g = \rho dV, \quad dV = \pi R^2 dH, \quad \text{or} \quad \rho = \frac{\mu P}{RT} = \rho_0 P_r, \tag{18}$$

where V is gas volume [m^3], ρ is gas density [kg/m^3], ρ_1 is gas density at altitude H_1. If we substitute P_r from Eq. (1), integrate, and substitute F_r from Eq. (8), we have

$$M_g = \frac{\pi \rho_1 R_1^2}{a + \dfrac{2\pi g}{k}} \left[F_r(H_1) - F_r(H_2) \right], \tag{19}$$

where lower index (subscript) “1” means values for lower end of tower and subscript “2” means values for top end of tower. The relative (dimensionless) gas mass is

$$M_{g,r} = \frac{M_g}{\rho_1 R_1^2} = \frac{\pi}{a + \dfrac{2\pi g}{k}} \left[F_r(H_1) - F_r(H_2) \right] \tag{20}$$

1.3.9 Computation of base radius

We get the base tower radius from Eq. (8) under the condition $F = gW$:

$$R_1 = \left(\frac{gW}{\pi P_1 R_r} \right)^{1/2}, \tag{21}$$

where W is the top load.

1.3.10 Computation of tower mass M

The mass of the tower, including the inside gas, is given by

$$M = \pi R_1^2 P_1. \tag{22}$$

1.3.11 Distance L of Earth view from the tower

The Earth view distance is important for communication, cell-telephones, radiolocation and tourists. This distance may be computed for a high tower by using the relationship:

$$L \approx \left(2R_eH + H^2\right)^{1/2}, \tag{23}$$

where $R_e = 6,378$ km is the Earth's radius. Results of computations are presented in (Bolonkin, 2003i, Figs. 4 and 5).

1.4 Macro Project 1. An Air Tower of 3 km Height

Design values: Base radius = 5 m, $K = 0.1$.

This inexpensive project provides experience in design and construction of a tall pneumatic tower, and of its stability. The project also provides funds from tourism, radio and television. The pneumatic tower has a height of 3 km. Tourists will not need a special suit or breathing device at this altitude. They can enjoy an Earth panorama of a radius of up 200 km. The bravest of them could experience 20 seconds of free-fall time followed by 2g overload.

1.4.1 Results of computations

Assume the additional air pressure is 0.2 atm (1atm $= 1.013 \cdot 10^5$ N/m^2), air temperature is 288 K (15°C, 60°F), base radius of tower is 5 m, $K = 0.1$. If the tower cone is optimal, the tower top radius must be 4.55 m. The maximum useful tower top lift is 92 tons. The cover thickness is 0.174 mm at the base and 0.114 mm at the top. The outer cover mass is only 23 tons (Bolonkin, 2003i, Fig. 9). If we add light internal partitions, the total cover weight will be about 32–36 tons (compared to 3 million tons for the 553 m CNN tower in Toronto). Maximum safely bending moment ranges from 780 ton· meter (at the base) to 420 ton·meter at the tower top. Other variants and more detail computations may be found in Bolonkin, (2003i, Figs. 6–10).

The expansion load is approximately 15 tons for a wind speed 30 m/s. It decreases the maximum useful top load to 77 = 92-15 tons.

1.4.2 Economic efficiency

Assume the cost of the tower is $5 million, its life time is only 10 years, annual maintenance $1 million, the number of tourists at the tower top is 200 (15 tons), time/tourist at the tower top is 0.5 hour, and the tower is open 12 hours per day. Then 4800 tourists will visit the tower per day, or 1.7 million per year. The unit cost of one tourist is $(0.5 + 1)/1.7 = 1$ $/person. If a ticket costs $9, the profit is $1.7 \times 8 = \$13.6$ million per year. If for a drop from the tower (in a special cabin, for a free-fall (weightlessness) time of 20 seconds, followed by a overload of 2g) costs each individual $5 and 20% of tourists take it, the additional profit will be $1.7 million.

1.5 Macro Project 2. Helium Tower of Height 30 km

Design values: Base radius = 5 m, $K = 0.1$.

Let us take the additional pressure over atmospheric pressure as 0.1 atm ($1 \cdot 10^4$ Pa). For $K = 0.1$, the radius is 2 m at an altitude of 30 km. For $K = 0.1$ the useful lift force it is about 75 ton-force at an altitude of 30 km, thus it is a factor of two times greater than the 3 km air tower. It is not surprising, because the helium is lighter than the air and it provides a lift force. The cover thickness changes from 0.08 mm (at the base) to 0.42 mm at an altitude of 9 km and decreases to 0.2 mm at 30 km. The outer cover mass is about 370 tons. Required helium mass is 190 tons. The tourist capability of this tower is twice than that of the 3 km tower, but all tourists must stay in an-tight cabins. The reader will find other variants and more detail computations in Bolonkin, (2003i, Figs. 11–16).

1.6 Macro Project 3. Air-hydrogen Tower of Height 100 km

Design values: Base radius of air part = 25 m, the hydrogen part has base radius = 5 m.

This tower consists of two parts. The lower part (0–15 km) is filled with air. The top part (15–100 km) is filled with hydrogen. It makes this tower safer, because the low atmospheric pressure at high altitude decreases the probability of fire. Both parts may be used for tourists.

1.6.1 Air part, 0–15 km

The base radius is 25 m, the additional pressure is 0.1 atm, average temperature is 240 °K, and the stress coefficient $K = 0.1$. This tower can be used for tourism and as an astronomy observatory. For $K = 0.1$, the lower (0–15 km) part of the project requires 570 tons of outer cover and provides 90 tons-force of useful top lift force. The reader may find other variants and more detail computations in Bolonkin (2003i, Figs. 17–21).

1.6.2 Hydrogen part, 15–100 km

This part has the base radius of 5 m, the additional gas pressure is 0.1 atm. A stronger cover is needed, with $K = 0.2$. The useful top tower load can be about 5 tons, maximum, for $K = 0.2$. The cover mass is 112 tons, the hydrogen lift force is 37 tons-force. The top tower will press on the lower part with a force of only $112 - 37 + 5 = 80$ tons-force. The lower part can support 90 tons. Other variants may be found in Bolonkin (2003i, Figs. 22–27). The proposed projects use an optimal change of the radius, but designers must find the optimal combination of the air and gas parts.

2. CABLE SPACE TOWERS

2.1 Introduction

This section suggests a very simple and inexpensive method and installation for lifting and launching payload into space. This method is different from the centrifugal method (2002, 2002a, 2002b, 2002c; 2003b, 2003d, 2003e; 2005d) in which a cable, circular or semi-circular in shape, and a centrifugal force, are used to keep the space station at high altitude. In the present method there is a straight line vertical cable connecting the space station to the Earth's surface. The space station is held in place by reflected cable and cable kinetic (shot) energy. The present method spends less energy in air drag.

This is a new method and transport system for delivering payloads and people into space. This method uses a cable and any conventional engine (mechanical, electrical, gas turbines) located on the ground. After completing an exhaustive literature and patent search, we decided that no similar method was proposed previously. However, earlier proposals to use kinetic energy to support a tower have been made by Yunitskii (1982), Lofstrom (1983, 1985), Hyde (1988), and Forward (1995). Differences between these earlier concepts and the designs analyzed here are discussed in section 2.5. Also, note that current access to outer space is described in Bolonkin (2002a–2005a), Smitherman (2000) and Space Technology (1996–1997).

2.2 Technical Solution

2.2.1 Brief description

The installation includes (see notations in Figs. 3 to 6): a strong closed-loop cable, rollers, a conventional engine, a space station (top platform), a load elevator and support stabilizing cables (expansions).

The installation works in the following way. The engine rotates the bottom roller and permanently moves the closed-loop cable at high speed. The cable reaches a top roller at high altitude, turns back and moves to the bottom roller. When the cable turns back it creates a reflected (centrifugal) force. This force can easily be calculated by using a centrifugal theory or a reflection (momentum) theory. The force keeps the space station suspended at the top roller; and the cable (or special cabin) allows the delivery of a load to the space station. The station has a parachute that saves people if the cable or engine fails.

The theory shows that currently produced artificial fibers allow the cable to reach altitudes up to 100 km (see Projects 1 and 2 below). If higher altitude is required a multi-stage tower must be used (Fig. 4, see also Project 3). If a very high altitude is needed (geosynchronous orbit or more), a very strong cable made from nanotubes must be used (see Project 4).

The tower may be used for a horizon launch of the space apparatus (Fig. 5). The vertical cable towers support horizontal closed-loop cables rotated by the vertical cables. The space apparatus is lifted by the vertical cable, connected to horizontal cable and accelerated to the required velocity.

The closed-loop cable may have variable length. This allows the system to start from zero altitude, and gives its workers/users the ability to increase the station altitude to a required value, and to spool the cable for repair. The innovation device for this action is shown in Fig. 6. The spool can reel up and unreel in the left and right branches of the cable at different speeds and can alter the length of the cable.

The safety speed of the cable spool is the same with the safety speed of the cable because the spool operates as a free roller. The conventional rollers made of the composite cable material have the same safety speed with the cable. The proposed spool is an innovation, because it consists only of cable (no core) and it allows reeling up and unreeling simultaneously with different speed. This is necessary to change the tower altitude.

The lower (ground) conventional drive roller is shown in Fig. 3 (see Chapter 10). The small drive rollers 25 Fig. 3 (Chapter 10) press the cable to main (large) drive roller, provide a high friction force between the cable and the drive rollers and pull (rotate) the cable loop.

The drive roller 3 in Fig. 6 (variable cable spool) is a row of double drive rollers which press the cable between them, create the high friction force and rotate the cable loop.

2.2.2 Advantages

The proposed towers and launch system are more advantageous as compared to the currently proposed towers and rocket systems:

1. They allow a very high altitude (up to geosynchronous orbit and more) to be reached, which is structurally impossible for solid material towers.
2. They are cheaper by some thousands of times than the current low high towers. No expensive rockets are required.
3. The cable towers may be used for tourism, power, TV and radio signal relay over a very wide area, as a radio locator, as well as space launchers.
4. The proposed towers and space launchers decrease the delivery cost at high altitude up to \$2–\$10 per kg.
5. The proposed space tower launcher may be built in a few months, whereas the modern rocket launch system requires years for development, design, and building.
6. The proposed cable towers and space launcher do not require high technology and may be produced by any non-industrial country from currently available artificial fibers.
7. Rocket fuel is increasingly expensive. The proposed cable towers and space launcher can use the cheapest sources of energy such as wind, water or nuclear power, or the cheapest fuels such as gas, coal, peat, etc., because the engine is located on the Earth’s surface. The flywheels may be used as an accumulator of energy.
8. There is no necessity to have highly qualified personnel such as rocket specialists with high salaries.
9. We can launch thousands of tons of useful payloads annually.

The advantages of the method are the same as for the centrifugal and cable launcher (Bolonkin, 1965–Bolonkin, 2005). The suggested method is approximately half the cost of the semi-circle launcher because it uses only one double vertical cable. It also has approximately half the delivery cost (up to \$2–10 per kg), because it has half the air drag and fuel consumption.

2.2.3 Cable properties

The reader may find details about the cable in Chapter 10 and about the cable characteristics in Galasso (1989), Dresselhous (2000), Carbon Fibers (1995). In the projects 1–3 below we are using only cheap artificial fibers widely produced by current industry.

2.3 Theory of the Cable Tower and Launcher

2.3.1 Lift force of the cable tower

Take a small part of the rotational circle and write the mechanical equilibrium relation (see Fig. 7 in Chapter 10):

$$\frac{2SR\alpha\gamma V^2}{R} = 2S\sigma \sin\alpha\,, \tag{24}$$

where V is rotational cable speed, R is circle radius, α is the angle of the circular part, S is cross-section of cable areas, σ is cable stress, γ is cable density. When $\alpha \to 0$ the relationship between the maximum rotational speed V and the tensile stress of the closed loop (curve) cable is

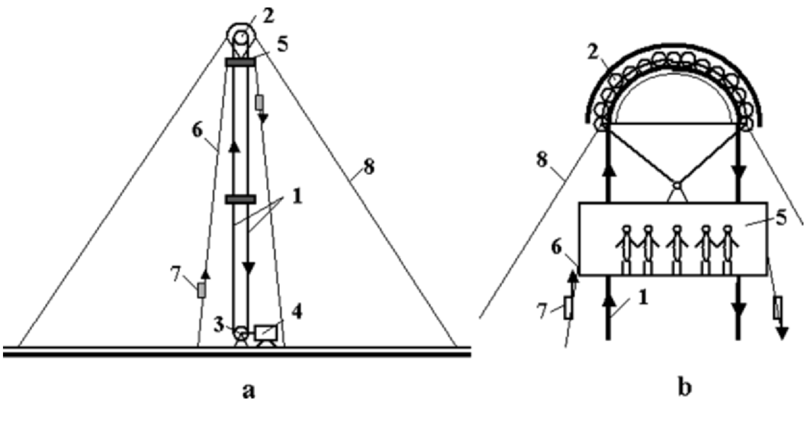

Figure 3. (a). Offered cable tower: 1 – mobile closed loop cable; 2 – top roller of the tower; 3 – bottom roller of the tower; 4 – engine; 5 – space station; 6 – elevator; 7 – load cabin; 8 – tensile element (stabilizing rope). (b). Design of top roller

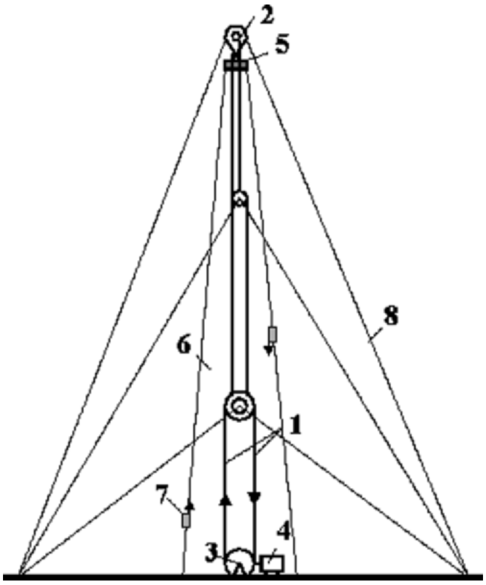

Figure 4. Multi-stage cable tower. Notations are same as Fig. 3

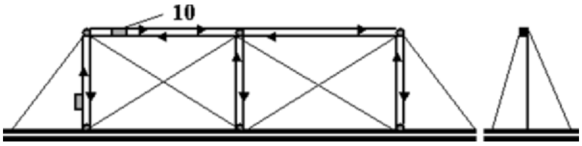

Figure 5. a. Kinetic space installation with horizontally accelerated parts. b. 10 – missile

$$V = \sqrt{\frac{\sigma}{\gamma}} = \sqrt{k}\,, \quad \text{the lift force is} \quad F = 2\sigma S, \tag{25}$$

where F is the lift force, $k = \sigma/\gamma$ is the relative cable stress. The computations of the speed for intervals $K = 0$ to 1, and 1 to 10, respectively, ($K = k/10^7$) are presented in Figs. 7 and 8. We shall find the lift force of the proposed installation from ordinary mechanics. Writing the momentum of the reflected mass per unit time (one second) we find:

$$\begin{aligned} &F = mV - (-mV) = 2mV, \quad m = \gamma S V, \\ &\text{and finally} \quad F = 2\gamma S V^2 \end{aligned} \tag{26}$$

where m is the cable reflected mass per unit time (one second). If we substitute Eq. (25) in Eq. (26), the same expression for the lift force $F = 2\sigma S$ will be found.

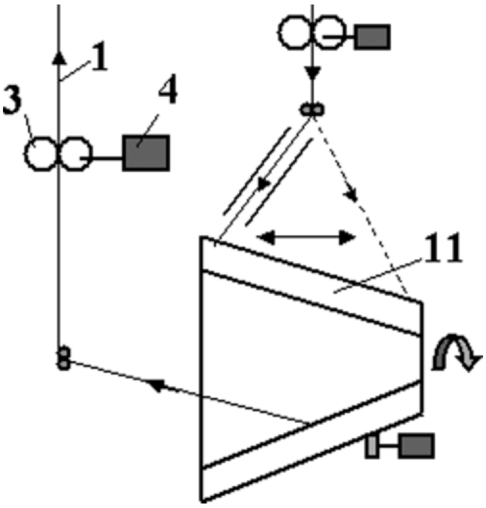

Figure 6. Variable cable spool at ground. 1–cable, 3–rollers, 4–engines, 11–cable spool

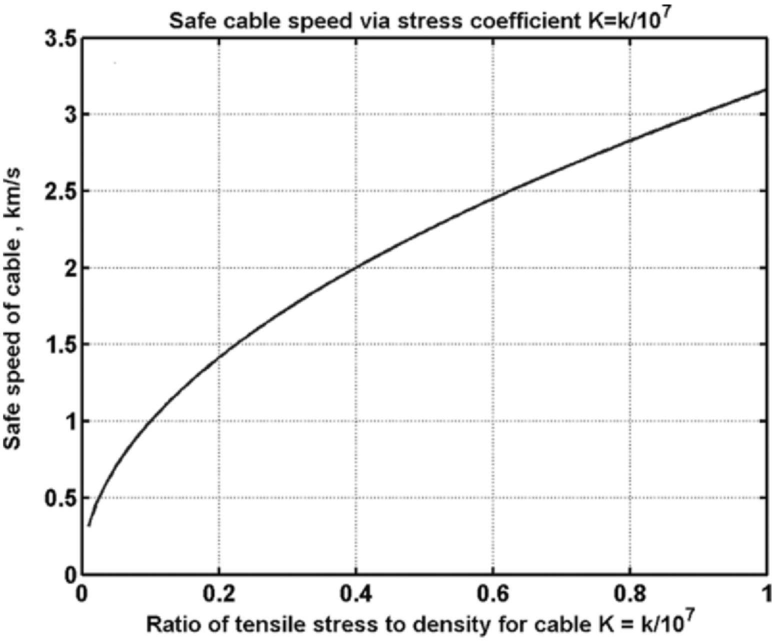

Figure 7. Safe cable speed versus safe stress coefficient $K = 0\text{–}1$. K is in $(\mathrm{m}^2/\mathrm{s}^2)/10^7$

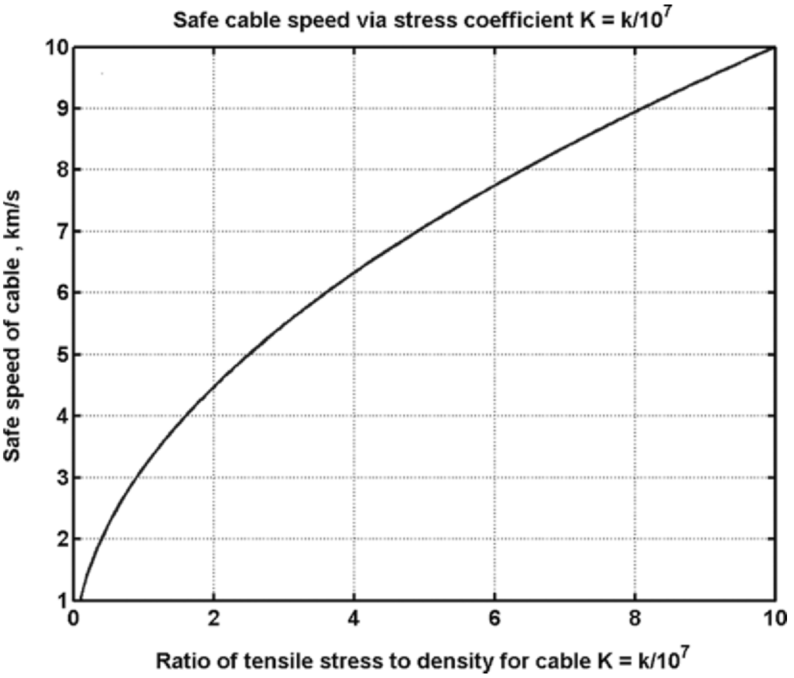

Figure 8. Safe cable speed versus relative stress coefficient $K = 1\text{–}10$, $(\mathrm{m}^2/\mathrm{s}^2)/10^7$

2.3.2 *Lift force in constant or variable gravity fields*

In a constant gravity field without air drag, the lift force of the proposed device equals the centrifugal force F minus the cable weight W:

$$F_g = F - W = F - 2\gamma gSH = 2\gamma S(V^2 - gH) = \\ 2S(\sigma - \gamma gH) = 2S\gamma(k - gH), \tag{27}$$

where H is the altitude of the cable tower.

The maximum tower height and the minimum cable speed in a constant gravity field are given by, respectively, (see Eq. 27):

$$H_{\max} = \frac{\sigma}{g\gamma} = \frac{k}{g}, \quad V_{\min} = \sqrt{gH}. \tag{28}$$

Results of computations are presented in Figs. 9 and 10. In this case the installation does not produce a useful lift force and will support only itself.

Now we find a kinetic lift force, F_g, in a variable gravity field and for the rotating Earth. The weight of cable in differential form is

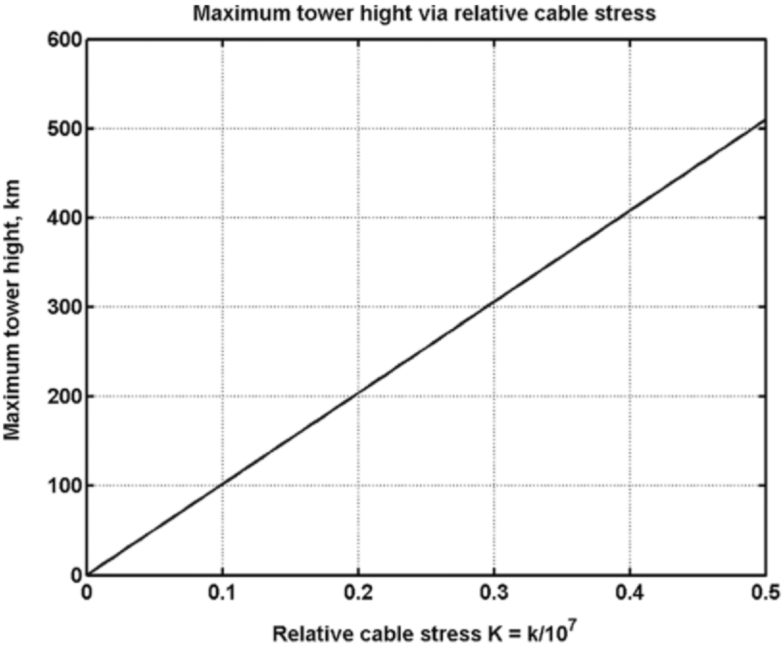

Figure 9. Maximum tower height versus relative cable stress. K is in $(\mathrm{m}^2/\mathrm{s}^2)/10^7$

$$\text{(29a,b)}\quad dP = \left(g - \frac{V^2}{R}\right) dm, \quad g = g_0\left(\frac{R_0}{R}\right)^2,$$

where

$$\text{(30)}\qquad \frac{V^2}{R} = \omega^2 R\,, \quad dm = \gamma S dR\,, \quad R = R_0 + H$$

The following integral is computed:

$$\text{(31)}\qquad P = \int_{R_0}^{R}\left[g_0\left(\frac{R_0}{R}\right)^2 - \omega^2 R\right]\gamma S dR = g_0\left(R_0 - \frac{R_0^2}{R}\right) - \frac{\omega^2}{2}\left(R^2 - R_0^2\right),$$

and the final equation for the kinetic lift force is

$$\text{(32)}\quad F_g = 2\sigma S - 2P = 2\gamma S k - 2P = 2\gamma S\left[k - g_0\left(R_0 - \frac{R_0^2}{R}\right) + \frac{\omega^2}{2}\left(R^2 - R_0^2\right)\right],$$

where

$$\text{(33)}\qquad k = \frac{\sigma}{\gamma} = V^2, \ R = R_0 + H.$$

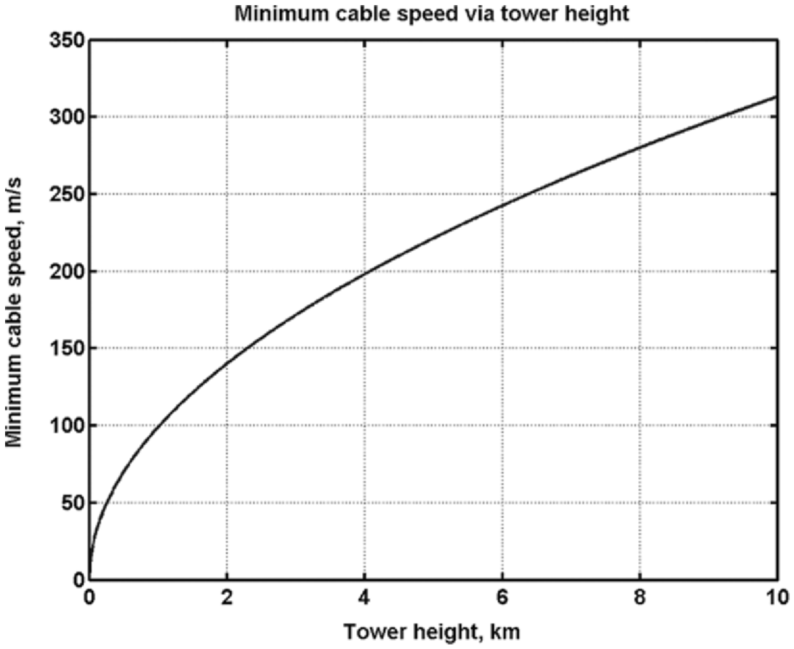

Figure 10. Minimum caple speed versus tower height

Here P is an auxiliary force resulting from the cable weight for a variable gravity field and the rotational Earth while ω is the Earth angular speed. Minimum cable stress and minimum cable speed of a variable rotating planet equals

$$(34) \qquad k_{\min} = g_0 \left(R_0 - \frac{R_0^2}{R} \right) - \frac{\omega^2}{2} \left(R^2 - R_0^2 \right),$$

$$(35) \qquad V_{\min}^2 = g_0 \left(R_0 - \frac{R_0^2}{R} \right) - \frac{\omega^2}{2} \left(R^2 - R_0^2 \right).$$

Results obtained by using these equations for Earth are presented in Figs. 11 and 12. If $K > 5$ the height of the cable tower may be beyond the Earth's geosynchronous orbit. For Mars, this condition is fulfilled for $K > 1$, while in case of the Moon the condition is $K > 0.3$. From Fig. 11 one can see that the proposed tower, of height 145,000 km, can be maintained without a cable rotation, and if the tower height is more 145,000 km, the tower has a useful lift force that allows a payload to be lifted using an immobile cable.

2.3.3 Estimation of cable friction in the air

Estimation of cable friction in air is difficult, mainly because there are no experimental data for air friction for an infinitely thin cable (especially at hypersonic

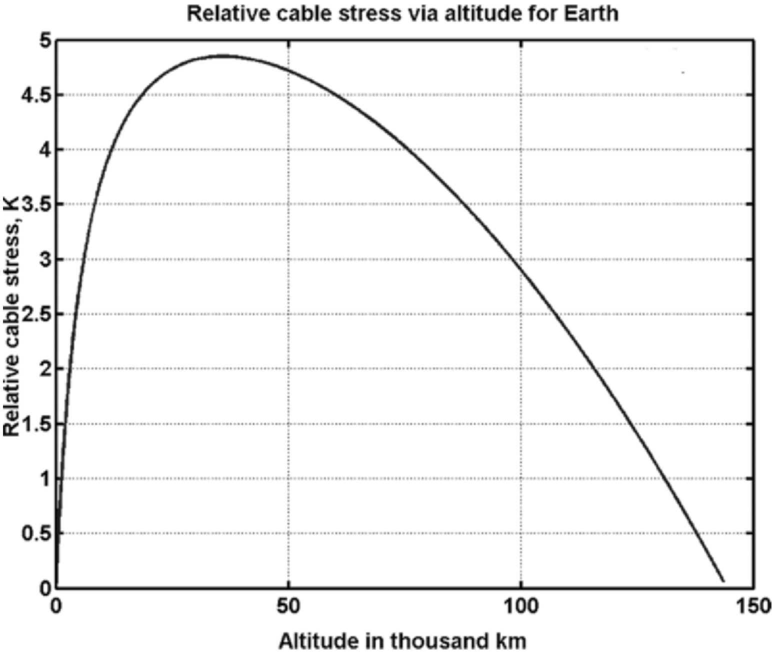

Figure 11. Relative cable stress versus altitude for rotational Earth with variable gravity

speeds). A computational method for plates at hypersonic speed described in the book by Anderson (1989, p. 287), was used. The computation is made for two cases: laminar and turbulent boundary layers.

The results of this comparison are very different. Turbulent friction is greater than laminar friction by hundreds of times. About 80% of the friction drag occurs in the troposphere (height from 0 to 12 km). If the cable end is located on a mountain at 4 km altitude, the maximum air friction will be decreased by 30%.

It is postulated that half of the cable surface will have the laminar boundary layer because a small wind or trajectory angle will blow away the turbulent layer and restore the laminar flow. The blowing away of the turbulent boundary layer is usual in aviation and it is used to restore laminar flow and decrease air friction. The laminar flow decreases the friction in hypersonic flow by about 280 times. If half of the cable surface has a laminar layer, it means that we must decrease the air drag calculated for full turbulent layer by minimum two times.

Below, the relationships proposed in Anderson (1989) to compute the local air friction for a two-sided plate are summarized:

$$(36)\qquad \frac{T^*}{T} = 1 + 0.032M^2 + 0.58\left(\frac{T_w}{T} - 1\right),$$

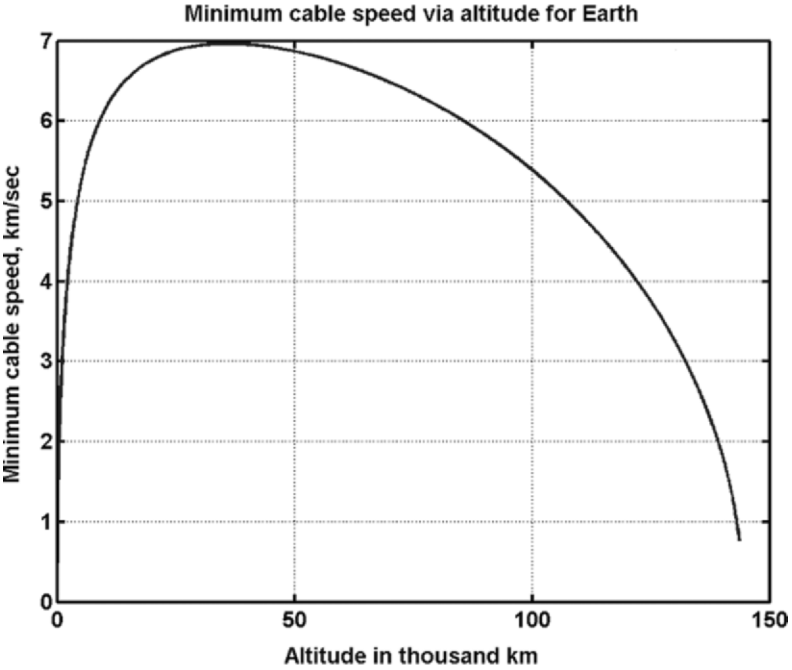

Figure 12. Minimum cable speed versue altitude for rotational Earth with variable gravity

$$(37)\qquad M=\frac{V}{a}\,,\quad \mu^{*}=1.458\times 10^{6}\frac{T^{*1.5}}{T^{*}+110.4}\,,$$

$$(38)\qquad \rho^{*}=\frac{\rho T}{T^{*}}\,,\quad R_{e}^{*}=\frac{\rho^{*}Vx}{T^{*}}\,,$$

$$(39)\qquad C_{f,L}=\frac{0.664}{(R_{e}^{*})^{0.5}}\,,\quad C_{f,T}=\frac{0.0592}{(R_{e}^{*})^{0.2}}\,,$$

$$(40)\qquad D_{L}=0.5C_{f.l}\rho^{*}V^{2}S,\quad D_{T}=0.5C_{f.t}\rho^{*}V^{2}S.$$

Where T^*, Re^*, ρ^*, μ^* are the reference (evaluated) temperature, Reynolds number, air density, and air viscosity, respectively. M is the Mach number, a is the speed of sound, V is speed, x is the length of the plate (distance from the beginning of the cable), T is flow temperature, T_w is body temperature, $C_{f.l}$ is a local skin friction coefficient for laminar flow, $C_{f,t}$ is a local skin friction coefficient for turbulent flow. Also, S is the area of skin of both plate sides, so this means for the cable we must take $0.5S$.

It can be shown that the general air drag D for the cable is obtained from linear superposition between the turbulent drag D_T and the laminar drag D_L (i.e. $D=0.5D_T+0.5D_L$).

From Eq. (40) we can derive the following relations for turbulent and laminar drags of the *vertical cable*:

$$D_T = \frac{0.0592\pi d}{4}\rho_0^{0.8}\left(\frac{T}{T^*}\right)^{0.8}\mu^{0.2}V^{1.8}\int_{H_0}^{H} h^{-0.2}e^{0.8bh}dh =$$

$$0.0547d\left(\frac{T}{T^*}\right)^{0.8}\mu^{0.2}V^{1.8}\int_{H_0}^{H} h^{-0.2}e^{0.8bh}dh, \tag{41}$$

$$D_L = \frac{0.664\pi d}{4}\rho_0^{0.5}\left(\frac{T}{T^*}\right)^{0.5}\mu^{0.5}V^{1.5}\int_{H_0}^{H} h^{-0.5}e^{0.5bh}dh =$$

$$0.5766d\left(\frac{T}{T^*}\right)^{0.5}\mu^{0.5}V^{1.5}\int_{H_0}^{H} h^{-0.5}e^{0.5bh}dh, \tag{42}$$

where d is the diameter of the cable and $\rho_o = 1.225$ kg/m^3 is air density at altitude $H = 0$.

The laminar drag is smaller than the turbulent drag by 200–300 times and we can neglect it. Engine power P and additional cable stress may be computed by conventional relationships:

$$P = 2DV, \quad \sigma = \pm\frac{D}{S} = \pm\frac{4D}{\pi d}\,. \tag{43}$$

The factor 2 entering Eq. (43) is a result of the two branches of the cable: one moves up and the other moves down. The drag does not decrease the lift force because in different branches the drag is in opposite directions. Computations were performed and some results are presented in Figs. 13 and 14.

2.3.4 *Security of visitors*

If the cable is damaged, people can be rescued using a parachute with variable area. The reader will find below relations describing the possibility of saving persons on the tower.

The parachute area is changed so that bodily overload does not go beyond a given value ($N < 5$g).

The differential equations describing the process of moving for passenger cabin are:

$$\frac{dH}{dV} = -V, \quad \frac{dV}{dt} = g - \frac{D}{m}, \tag{44}$$

$$\text{where } \frac{D}{m} = C_D\frac{\rho a V}{2p}, \quad p = \frac{0.5C_D\rho a V}{gN}, \tag{45}$$

$$p \geq 0, \quad \frac{D}{mg} \leq N, \tag{46}$$

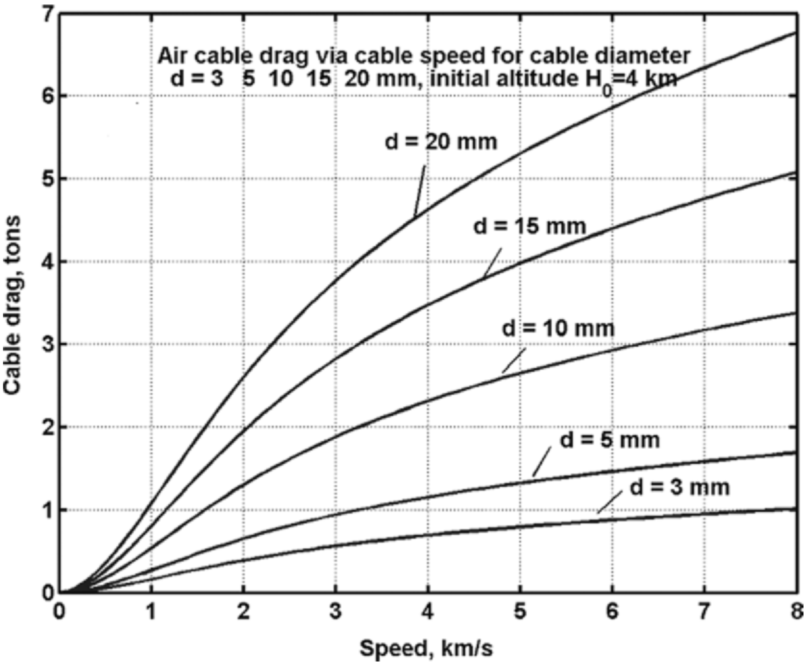

Figure 13. Air cable drag versus cable speed 2–8 km/s for different cable diameter

Here t is time, m is mass, N is the overload and p is the parachutes specific load. The equations for air density are (with H entering in meter):

$$\text{(47)} \qquad \text{for} \quad H = 0 - 10\,\text{km}, \quad \rho = 1.225e^{-H/9218},$$

$$\text{(48)} \qquad \text{for} \quad H > 10\,\text{km}, \quad \rho = 0.414e^{-(H-10000)/6719}.$$

Tourists can be rescued from altitudes up to 250–300 km. The professional astronauts can endure an overload up 8g and may be rescued from greater altitudes.

2.4 Macro-projects

2.4.1 Project 1. Cable tower of height 4 km

To build a 4 km height tower we may use a conventional artificial fiber widely produced by industry with the following cable properties: admissible (safe) stress is $\sigma = 180$ kg/mm^2 (maximum $\sigma = 600$ kg/mm^2, safety coefficient $n = 600/180 = 3.33$), density is $\gamma = 1800$ kg/m^3, cable diameter $d = 10$ mm.

The special stress is $k = \sigma/\gamma = 10^6$ m^2/s^2 ($K = k/10^7 = 0.1$), safe cable speed is $V = k^{0.5} = 1000$ m/s, the cable cross-section area is $S = \pi d^2/4 = 78.5$ mm^2, useful

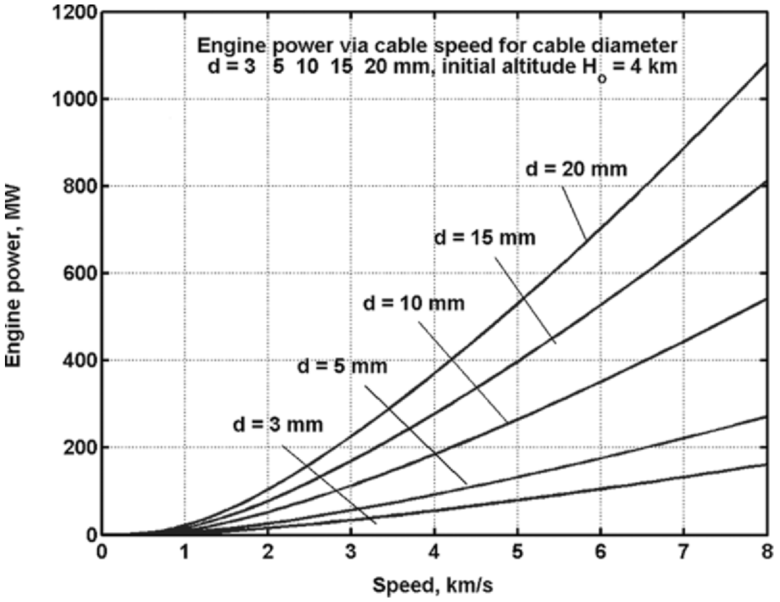

Figure 14. Engine power versus cable speed 2–8 km/s for different cable diameter

lift force is $F = 2S\gamma(k - go) = 27.13$tons-force. Requested engine power is $P =$ 16MW (Eq. 10), cable mass is $M = 2S\gamma H = 2\cdot 78.5\cdot 10^{-6}\cdot 1800\cdot 4000 = 1130$ kg.

Assume that the tower is used for tourism with a payload of 20 tons. This means $20000/75 = 267$ tourists may visit the station simultaneously. We take 200 tourists every 30 minutes, i.e. $200\cdot 48 = 9600$ people/day. Let's say 9000 tourists/day which corresponds to $90000\cdot 350 = 3.15$ million/year.

Assume the cost of installation is \$15 million, the life time is 10 years, and the maintenance cost is \$1 million per year. The cost to ensure services for a single tourist is $2.5/3.15 =$ \$0.8 per person.

The required fuel $G = Pt/\varepsilon\eta = 16\cdot 106\cdot 350\cdot 24\cdot 60\cdot 60/(42\cdot 106\cdot 0.3) = 38.4\cdot 10^6$ kg. If the fuel cost is \$0.25 per kg, the annual fuel cost is \$9.6 millions, or 9.6/3.15 = \$3.05 per person. Here t is annual time [s], ε is fuel heat capability [J/kg], and η is the engine efficiency.

The total production cost is $0.8 + 3.05 =$ \$3.85 per tourist. If a trip costs \$9, the annual profit is $(9 - 3.85)\cdot 3.15 = 16.22$ millions of US dollars.

2.4.2 Macro-project 2. Cable tower of height 75 km

To build a 75 km height tower one takes the admissible cable stress $K = 0.1$, the cross-section area $S = 90$ mm^2 ($d = 10.7$ mm), the cable density $\gamma = 1800$ kg/m^3. Then, the lift force is $F = 2S\gamma(k - gH) = 7$tons-force. The required engine power is $P = 11$ MW (Eq. 43, Fig. 14), cable mass is $M = 2S\gamma H = 2\cdot 90\cdot 10^{-6}.\cdot 75000 = 24.3$ tons and the cable speed is 1000 m/s.

2.4.3 Macro-project 3. Multi-Stages Cable tower of height 225 km

Current industry produces only a cheap artificial fiber with maximum stress $\sigma = 500$– 620kg/mm^2 and density $\gamma = 1800$ kg/m^3. We take an admissible stress $\sigma = 180$ kg/mm^2 (safety coefficient is $n = 600/180 = 3.33$), $\gamma = 1800$ kg/m^3. Then $k = \sigma/\gamma = 1000000$ N/m^2 and $K = k/10^7 = 0.1$. Using this cable one may design a one-stage cable tower with a maximum height 100 km (payload = 0). Assume we design a tower of height 225 km by using the present-day material. We may choose a 3- stage tower with each stage of height $H = 75$km and useful load capability $M_{3,p} = 3$tons at the tower top.

In this case the 3rd (top) stage (150–225 km) must have a cross-section area $S_3 = M_{3,p}/[2\gamma k - gH] = 33.3$ mm^2 ($d = 6.5$ mm) and the cable mass of the 3rd stage is $M_{3,c} = 2S_3\gamma H = 9$tons. Total mass of third stage is $M_3 = 9 + 3 = 12$ tons.

The 2nd stage (75–150 km) must have a cross-section area $S_2 = M_3/[2\gamma(k - gH)] =$ 133 mm^2 ($d = 13$ mm) and the cable mass of 2nd stage is $M_{2,c} = 2S_2\gamma H = 36$tons. Total mass of third + second stages is $M_2 = 12 + 36 = 48$ tons.

The 1st stage (0–75 km) must have cross-section area $S_1 = M_2/[2\gamma(k–gH)] =$ 533 mm^2 ($d = 26$ mm) and the cable mass of the 1st stage is $M_{1,c} = 2S_2\gamma H =$ 144tons. Total mass of third + second+ first stages is $M_0 = 48 + 144 = 192$ tons.

2.4.4 Macro-project 4. Cable tower with height 160,000 km

Assume that a nanotube cable is used, with $K = 6$ (for this height K must be more than 5, see Fig. 11). This means the admissible stress is $\sigma = 6,000$ kg/mm^2 and the cable density is $\gamma = 1000$ kg/m^3. Presently, the scientific laboratories produce nanotubes with $\sigma = 20,000$ kg/mm^2 and density $\gamma = 0.8$–1.8 kg/m^3. Theory predicts $\sigma = 100,000$ kg/mm^2. Industrial nanotubes production will become fully operable during the next 5–10 years.

Take a cross-section cable area of mm^2. The required speed is $V = (k)^{0.5} = (6\cdot 10^7)^{0.5} = 7.75$ km/s, the mass of cable is $M = S\gamma H = 320$ tons. When full altitude is reached the engine can be turned off and the centrifugal force of the Earth's rotational motion will support the cable. Moreover, the installation has a lift force of about 1000 kg-force, so a useful load can be connected to the cable, the engine can be turned on or slow speed and the load can be delivered into space.

2.4.5 Macro-project 5. Cable tower as Space Launcher

The installation of Fig. 5 may be used as a space launcher. The space apparatus is lifted to high altitude by the left cable tower, connected to the horizon line and accelerated. The required acceleration distance depends on the admissible acceleration. For a projectile it may be 10–50 km (overload is $N = 64$–320g), for astronauts it may be 400 km ($N = 8$g), for tourists it may be 1100 km ($N = 3$g).

2.5 Discussion and Historical Priorities

The project propose here offers a new, simpler, cheaper method for space launches. The project does not need expensive rockets as current methods do, or rockets to launch a counterbalance into space and thousands of tons of nanotubes cable as the NASA space elevator does. It only needs conventional fiber cable and a conventional engine located on a planetary surface.

Pneumatic (inflatable) space towers were proposed and theorized for the first time by Bolonkin (2002d, 2003i). Cable towers were proposed and theorized for the first time by 2002 (2002a, 2002b, 2002c, 2002e, 2003c, 2003d, 2003e, 2003f, 2003j, 2004a, 2005a, 2005b, 2005d). Other applications of these ideas may be found in papers published by the author during 1965–2005. Some of these works are accessible in the Internet (http://Bolonkin.narod.ru/p65.htm).

Other scientists contributed to this field and their findings are briefly presented in the following.

R. L. Forward (1995) offered the idea of a space installation. The project is called "the Space Fountain", for it holds objects up in space in the same way that a water fountain supports a ball bobbing at the top of its vertical jet. This would be done with a stream of pellets that would be shot from a space platform hovering motionless up at 2000 kilometers altitude to another platform partway around the Earth. When the projectiles reach the top of the tower, they are turned around by a large bending magnet. The projectiles reach the bottom of the tower with almost the same velocity that they had when they were launched. The stream of high speed projectiles is then bent through 90 degrees by a bending magnet so that it is traveling horizontally to the surface in an underground tunnel (4 km diameter). The projectile stream is then turned in a large circle by more bending magnets and energy is added by electromagnetic drivers to bring the projectiles back up to the original launch velocity. The installation needs in a gigantic vacuum rigid tower more 100 km for leave out atmospheric drag (see Fig. 5 in Forward, 1995). Some problems still remain to be solved. For example, the projectile has a speed 4 km/s at top station. Computations show that for turning down this projectile, the top station needs a magnet track some kilometers, weighting hundreds of tons-force and requiring a huge energy to operate. Designers have to find solutions how to support this very large weight and an appropriate energy source.

K. H. Lofstrom (1983, 1985, 2002) suggested a space launcher which uses free segmented iron ribbon. Lofstrom's launch idea is different from the cable tower project proposed here. The most important differences are:

1. The present project employs *a fiber cable (rope) which uses tensile stress*. The Lofsrom's idea employs a set of the free segmented iron plates (bullets of size $0.05 \cdot 0 \cdot 0076 \cdot 2\ \text{m}^3$) which hardly could keep tensile stress. Lofsrom's fabric ribbon also hardly could keep the tensile stress. The assumption of keeping the tensile stress is very important for Lofsrom's design because different parts of the bullets (chain ribbon) have different speed during a launch time. Both Lofstrom (and Forward) used the well-known idea of kinetic energy of *bullet* (projectile) for pressing. The present author uses the idea of kinetic energy of

cable for pressing (to our knowledge, there is no other device already built on the base of this idea).

2. Both Lofstrom's bullets and a support electromagnetic system are located into the double vacuum tubes. They need in electromagnets, a special electronic stability control along of all tracks, vacuum pumps, linear electromagnetic engines. These systems are very complex, have a high cost, and require a large amount of electric energy in operation. The present project requests *just* the strong open cable and this cable is used to move any sort of (mechanical or electrostatic) engine.
3. Lofsrom's construction is a *horizontal launcher* having 2000 km length and located at 80 km altitude. The suggested structure is variable *vertical tower* which may change altitude from zero to many kilometers.

An idea similar to Lofsrom's was early suggested by the Russian scientist A. Yunitskii (1982). Yunitskii's space system has also the two moved ribbons located into vacuum tube and moved by electromagnetic engines. The system can lift itself (and useful load) to space, to launch payload, and return to ground. Yunitskii's power space launcher is located as a gigantic ring around the Earth.

The present author offered the simplest space keeper and launcher as a rotated cable around the Earth in Bolonkin (2003d). Other research and comments on these topics may be found in Pokrovskii (1964), Poliakov (1977), Lofstrom (1983, 1985), Mayboroda (1988), Hyde (1988), Landis (1998, 2005) and Landis and Cafarelli (1995, 1999).

3. CONCLUSIONS

The presented theory and design method show that an inexpensive tall tower can be constructed and can be useful for industry, government and science. Cable (kinetic) towers are prospective as space towers and may be used in other fields of activity, too (Bolonkin, 2004a). The computation procedure developed here should be seen as a starting point for further research and development of the associated problems.

ACKNOWLEDGMENTS

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REFERENCES

Anderson JD (1989) Hypersonic and high temperature gas dynamics. McGraw-Hill Book Co, New York

Bolonkin AA (1965) Theory of flight vehicles with control radial force. Collection researches of flight dynamics. Mashinostroenie Publisher, Moscow, 1965, pp 79–118 (in Russian)

Bolonkin AA (2002a) Transport system for delivery tourists at altitude 140 km. IAC-02-IAA.1.3.03. 53rd International Astronautical Congress, The World Space Congress – 2002, Houston, Texas, USA. http://Bolonkin.narod.ru/p65.htm. Cited 10–19 Oct 2002

Bolonkin AA (2002b) Non-rocket Earth-Moon transport system, COSPAR-02 B0.3-F3.3–0032-02, 02-A-02226. 34th Scientific Assembly of the Committee on Space Research (COSPAR), The World Space Congress – 2002, Houston, Texas, USA, 10–19 October 2002

Bolonkin AA (2002c) Non-rocket Earth-Mars transport system, COSPAR-02 B0.4-C3.4–0036–02. 34th Scientific Assembly of the Committee on Space Research (COSPAR), The World Space Congress – 2002, Houston, Texas, USA, 10–19 October 2002

Bolonkin AA (2002d) Optimal inflatable space towers with 3–100 km height. Paper presented COSPAR-02-C1.1–0035–02. 34th Scientific Assembly of the Committee on Space Research, IAC–02–IAA.1.3.03. Presented at World Space Congress 2002, Houston, TX, USA, 10–19 October

Bolonkin AA (2002e) Inexpensive cable launcher of high capability, IAC-02-V.P.07. 53rd International Astronautical Congress, The World Space Congress–2002, Houston, Texas, USA, 10–19 October 2002

Bolonkin AA (2003a) Hypersonic space launcher. J Actual Problems Aviation Aerospace Systems, 8(1): pp. 45–58, Kazan, Daytona Beach

Bolonkin AA (2003b) Asteroids as propulsion systems of space ships. J Br Interplanet Soc 56(3–4):98–107

Bolonkin AA (2003c) Space cable launchers. Paper 8057 at International Air & Space Symposium – the Next 100 Years, Dayton, Ohio, USA, 14–17 July 2003

Bolonkin AA (2003d) Centrifugal keeper for space stations and satellites. J Br Interplanet Soc 56:314–322. http://Bolonkin.narod.ru/p65.htm

Bolonkin AA (2003e) Non-rocket Earth-Moon transport system. Adv Space Res 31(11):2485–2490

Bolonkin AA (2003f) Earth accelerator for space ships and missiles. J Br Interplanet Soc 56(11/12):394–404

Bolonkin AA (2003g) Air cable transport and bridges, TN 7567. International Air & Space Symposium – the Next 100 Years, Dayton, Ohio, USA, 14–17 July 2003

Bolonkin AA (2003h) Air cable transport system. J Aircraft 40(2):265–269

Bolonkin AA (2003i) Optimal inflatable space towers with 3–100 km height. J Br Interplanet Soc 56(3/4):87–97

Bolonkin, AA (2003j) Non-rocket transportation system for space travel. J Br Interplanet Soc 56:231–249

Bolonkin AA (2004a) Kinetic space towers and launchers. J Br Interplanet Soc 57(1/2): pp. 33–39

Bolonkin AA (2004b) Multi-reflex propulsion system for space and air vehicles. J Br Interplanet Soc 57(11/12):379–390

Bolonkin AA (2005a) High speed catapult aviation, AIAA-2005–6221. Atmospheric Flight Mechanic Conference – 2005, USA, 15–18 August, 2005

Bolonkin AA (2005b) Kinetic Anti–Gravitator, AIAA-2005–4504. 41th Propulsion Conference, Tucson, Arizona, USA, 10–12 July 2005

Bolonkin AA (2005c) Electrostatic Solar Wind Propulsion System, AIAA-2005–3857. 41th Propulsion Conference, Tucson, Arizona, USA, 10–13 July 2005

Bolonkin AA (2005d) Sling Rotary Space Launcher, AIAA-2005–4035. 41th Propulsion Conference, Tucson, Arizona, USA, 10–13 July 2005

Carbon and High Performance Fibers (1995) Directory, 6th edn. Chapman & Hall, London

Clarke AC (1978) Fountains of paradise. Harcourt Brace Jovanovich, New York

Dresselhous MS (2000) Carbon nanotubes. Springer, New York

Forward RL (1995) Indistinguishable from magic. Baen books, New York

Galasso FS (1989) Advanced fibers and composite. Gordon and Branch Science Publisher, London

Harris JT (1973) Advanced material and assembly methods for inflatable structures. AIAA, Paper no. 73–448

Hyde RA (1988) Earthbreak: A review of Earth-to-space transportation. In: Mark H, Wood L (eds) Energy in physics, war and peace. A festschrift celebrating Edward Teller's, 80th birthday. Kluwer Academic Publishers, Dordrecht, pp 283–307

Koell DE (2000) Handbook of cost engineering. TCS, Germany

Landis GA (1998) Compression structures for earth launch, Paper AIAA-98–3737. 24th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Cleveland OH, July 13–15

Landis GA (2005) Correction. J Br Interplanet Soc 58:58

Landis A, Cafarelli C (1995) The Tsiolkovski tower, Paper IAF-95-V.4.07. 46th International Astronautics Federation Congress, Oslo, Norway, 2–6 October 1995

Landis A, Cafarelli C (1999) The Tsiolkovski tower re-examined. J Br Interplanet Soc 32:176–180

Lofstrom KH (1983) The launch loop. Analog 103:67–80

Lofstrom KH (1985) The launch loop: A low cost Earth-to-high orbit launch system, Paper AIAA-85–1368. AIAA 21st Joint Propulsion Conference

Lofsrom KH (2002) http://www.launchloop.com/launchloop.pdf

Mayboroda A (1988) Zero gravity on earth. Yuniy Tehnik (Young Technician), No. 10 (in Russian)

Pokrovskii GI (1964) Space tower, *TM* (*Technology for Youth*), No. 10 (in Russian)

Poliakov G (1977) Space Necklace of Earth, TM (Technology for Youth), no. 4 (in Russian)

Smitherman DV Jr (2000) Space elevators. NASA/CP-2000–210429

Space Technology & Applications (1996–97) International forum, parts 1–3, Albuquerque, MN

Tsiolkovski KE (1959) Grezi o zemle i nebe, Moskva, Izd-vo AN SSSR. Speculations about Earth and Sky on Vesta, Academy of Sciences, USSR, Moscow, p 35

Yunitskii A(1982) General planetary transport system, TM (Technology for Youth), No. 6 (in Russian). (see Russian works in http://www.ipu.ru/stran/bod/ing/sovet2.htm, http://www.ipu.ru/stran/bod/ing/sovet_ris.htm)